ME 333

Manufacturing Processes II

Chapter 9

Powder Metallurgy Processing

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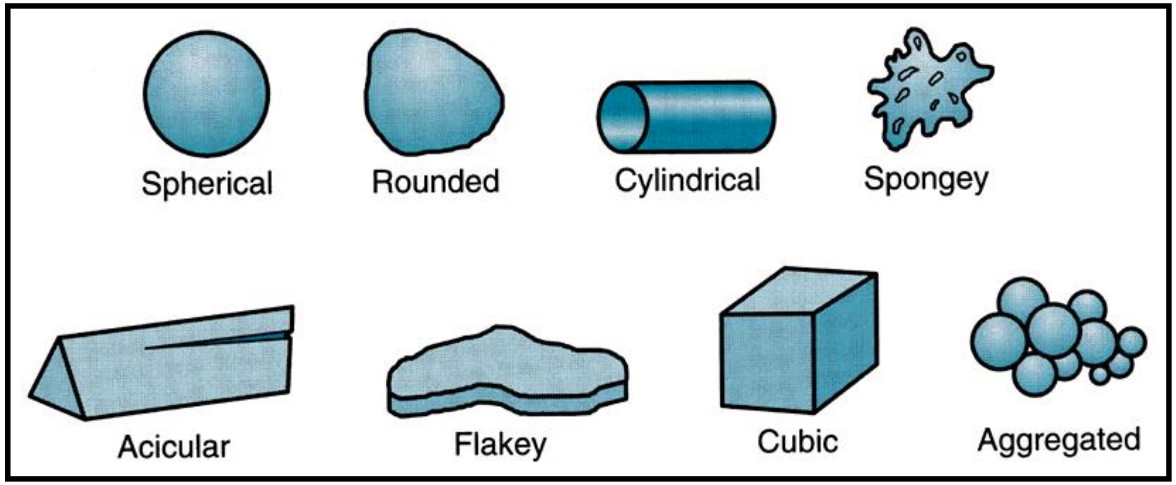
- **Powder Metallurgy (PM)** is the art of making commercial products from metallic powders by means of **pressure**. May or may not be used, **heat** must be kept at a temp. below the melting point of powder.
- PM is **an additive manufacturing process** as the parts are produced from metallic and/or nonmetallic powders.
- Metal powders may be mixed with other powders for **lubrication** or binding purposes.
- Metal powders and machines & dies are expensive. However, high cost is justified by the unusual properties obtained (some products cannot be made by other processes).
- PM is suitable for mass production of parts to net/near-net shape, and thus eliminating or reducing the need for subsequent machining.

1. **Shape:** Shape of powder particles depends upon its production method (spherical, dendritic, flat, or angular).



2. **Fineness:** The powders are sized with standard sieves of 36-850 μm. The particle size distribution affects flowability and apparent density.

3. **Flowability:** It is the ability of a powder to flow and fill a die cavity. In other words, it refers to the rate of flow through fixed orifice.

4. **Compressibility:** It is the ratio of volume of initial powder to volume of pressed compact, which varies considerably with the particle size distribution. **Green strength** of a compact (i.e. the strength before sintering) is dependent on compressibility.

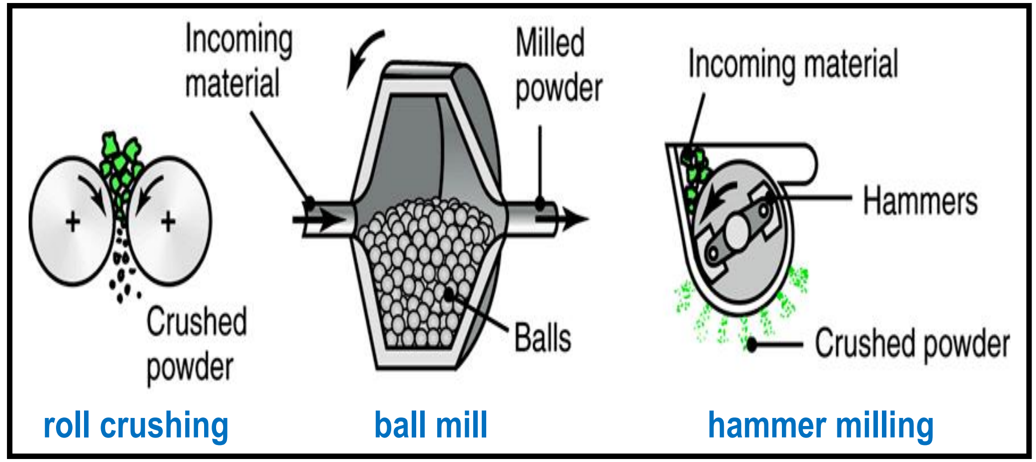
5. **Apparent Density:** It is the weight of powders occupying a certain volume (in g/cm^3).

6. **Sintering Ability:** Sintering is the bonding of particles by application of heat. Temperature range should be smaller than melting temperature of powder.

Due to individual physical and chemical characteristics, **metal powders are manufactured in different ways**. The procedure varies considerably resulting in different particle characteristics:

1. **Machining:** Results in coarse particles and used in production of magnesium powders.

2. **Milling:** Uses various types of crushers, rotary mills, etc. Brittle materials may be reduced to irregular shapes of almost any fineness. This process is also used for pigment production from ductile materials. Generally, oil is used as carrier medium.

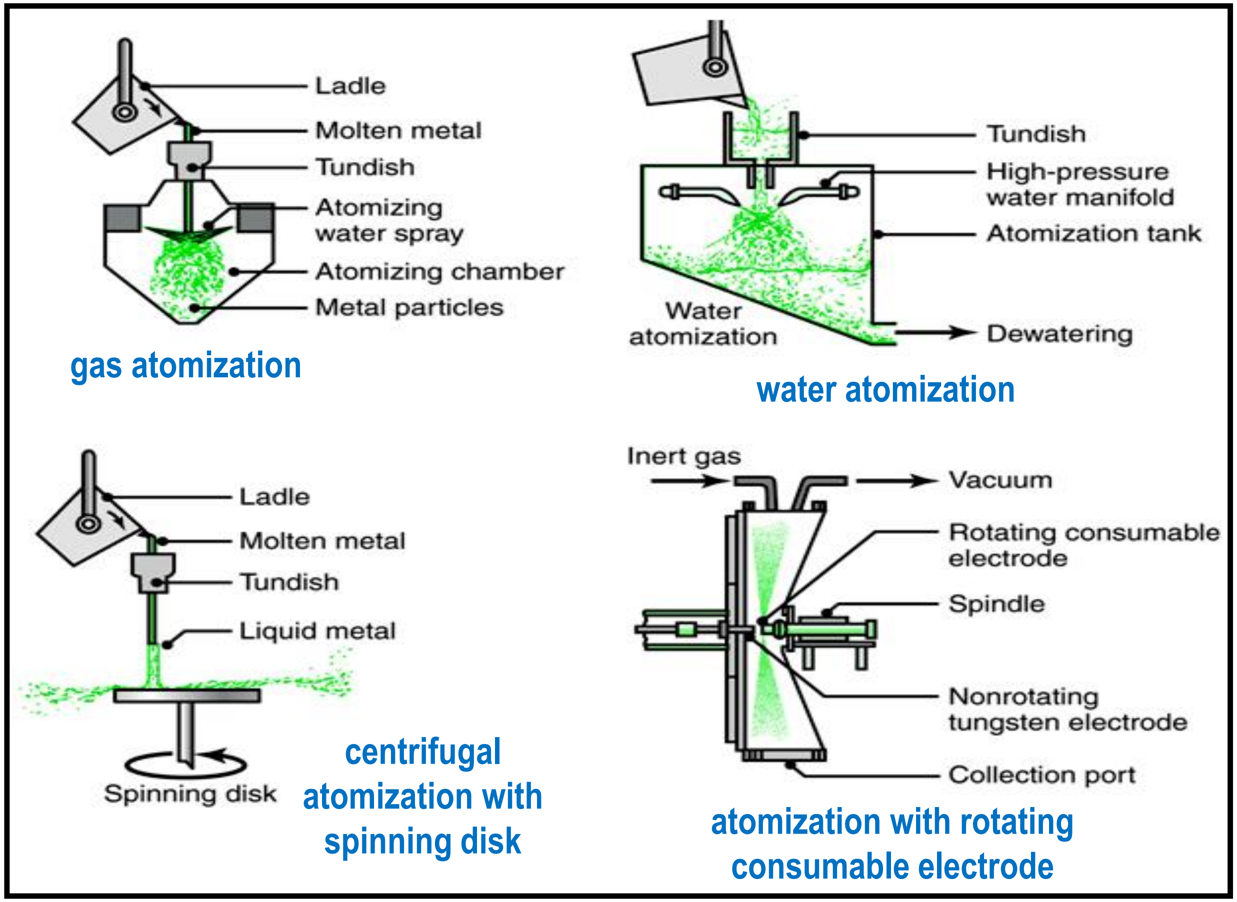


3. **Shotting:** Pouring the molten metal through an orifice slowly, and cooling by dropping into water. Spherical or pear-shaped particles are obtained. Particle size is too large for PM.

4. **Electrolytic Deposition:** Common method for producing iron, silver, tantalum and several other metals. For producing iron powder, steel plates are placed as anodes in electrolysis tanks and stainless steel is used as cathode. Direct current is passed through circuit, and iron powders are deposited on cathode. Being brittle in this condition, annealing is needed.

5. Direct Reduction: Reduces metal oxide mines to metal powder. Minerals are crushed to powder size, and reduced to metal powder under reducing atmospheres (rich in H or C). For producing iron powder, crushed iron oxide is fed into a rotating kiln along with crushed coke. Being heated up to *1050 °C*, carbon combines with oxygen and pure iron powder is obtained. It looks like a sponge, and so called as **"sponge iron"**.

6. Atomization: The most common metal powder production method. A metal stream is atomized by a pressurized fluid. It is very much in use for producing alloy steel powders. Powder size and shape can be controlled by controlling metal flow rate and pressure of atomizing jets.



gas atomization

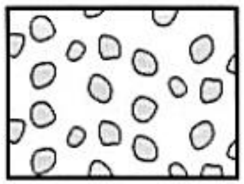
water atomization

centrifugal atomization with spinning disk

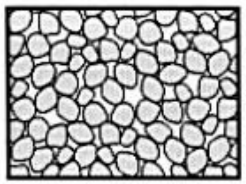
atomization with rotating consumable electrode

After the metallic powders have been produced and classified, the conventional PM process sequence consists of **three major steps**:

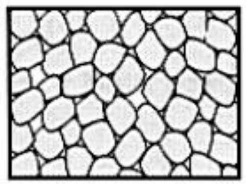
1. **Blending & mixing** of powders
2. **Compaction**
3. **Sintering** (and optional secondary and finishing operations)



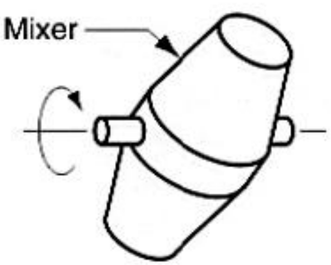
Blending & Mixing

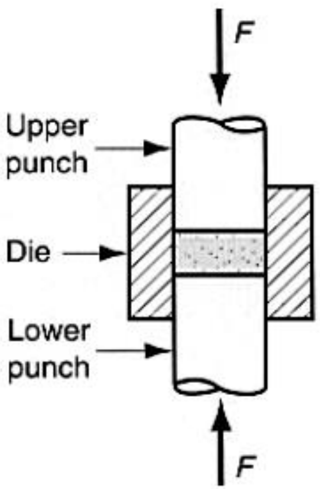


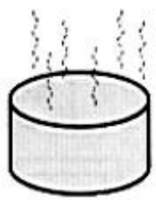
Compacting

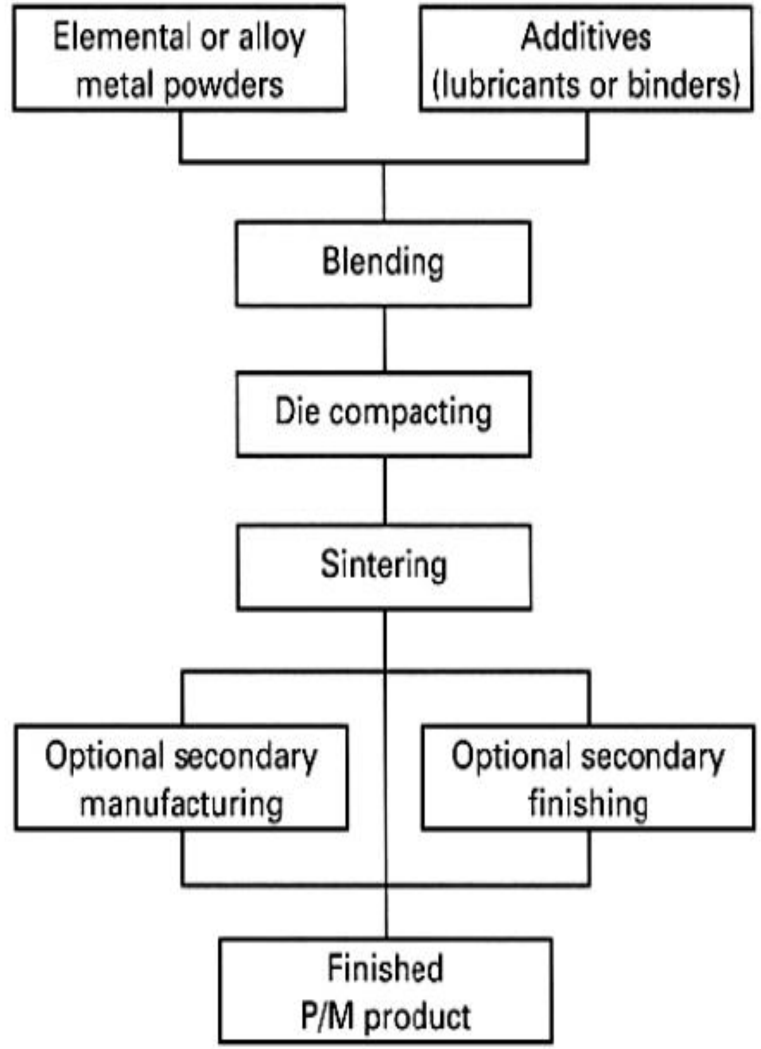


Sintering



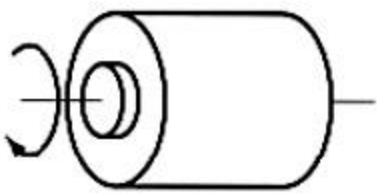




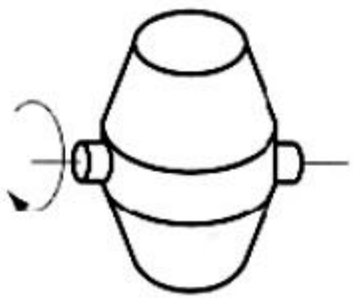


Blending & Mixing

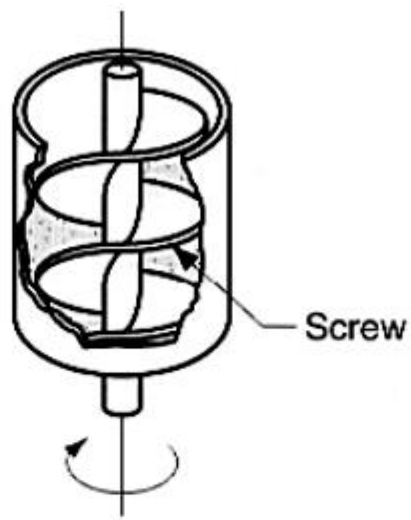
- **Blending:** Mixing powder of the same chemical composition but different sizes.
- **Mixing:** Combining powders of different chemistries.
- Blending and mixing are accomplished by **mechanical means** (*as illustrated below*).
- Apart from powders, **some other ingredients** are usually added:
  - **Lubricants:** to reduce the particles-die friction (*stearates of zinc & aluminium*)
  - **Binders:** to achieve sufficient strength before sintering (*contain epoxy resin*)
  - **Deflocculants:** to improve the flow characteristics during feeding



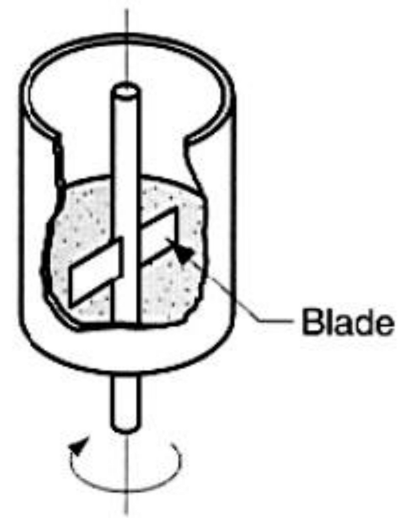
rotating drum



rotating double cone

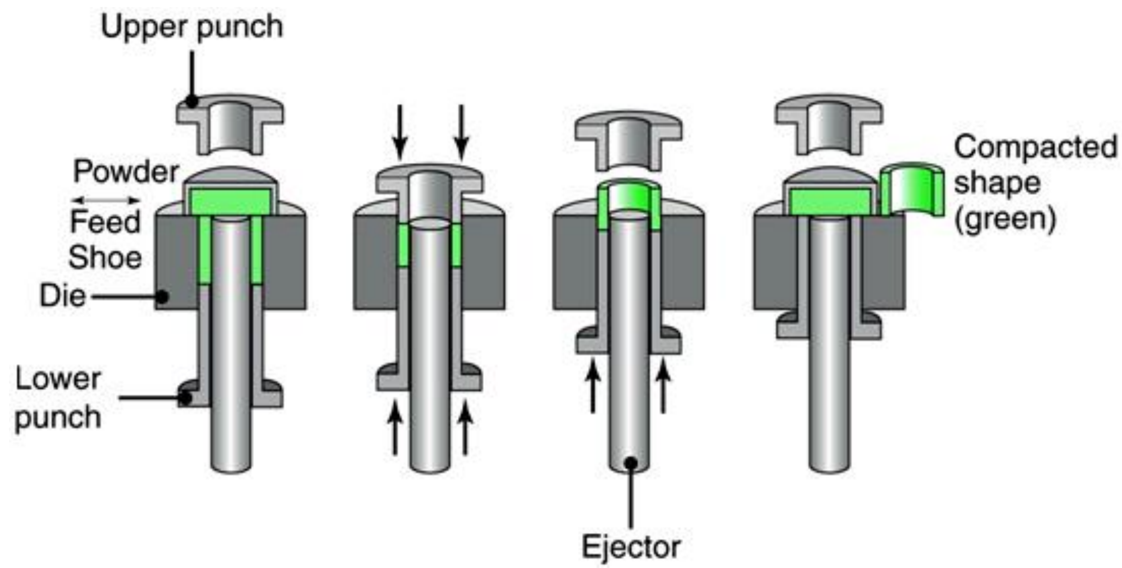


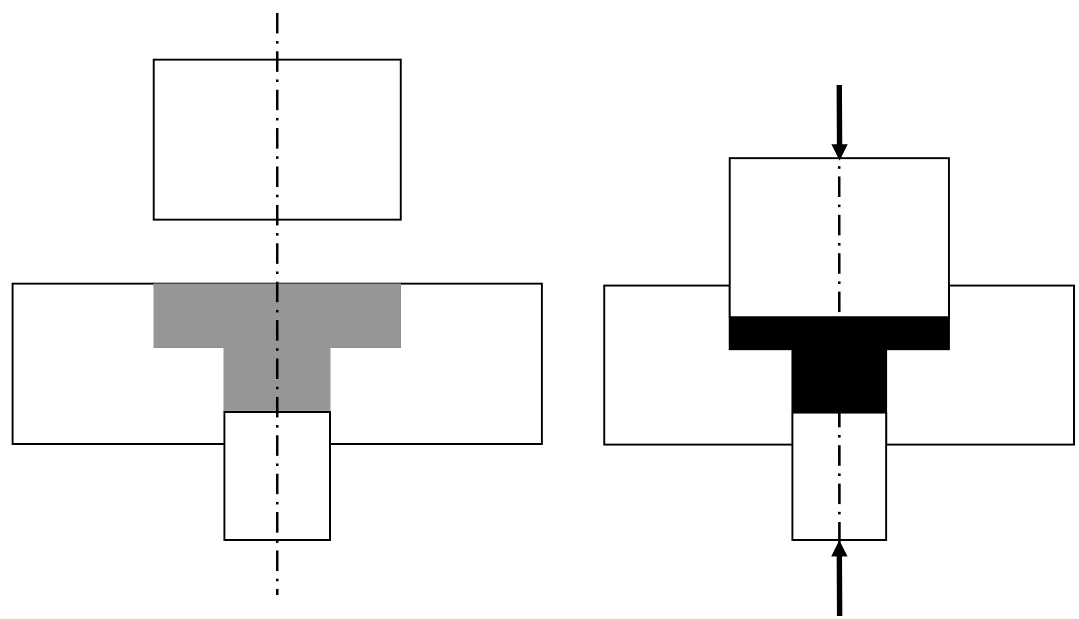
screw mixer



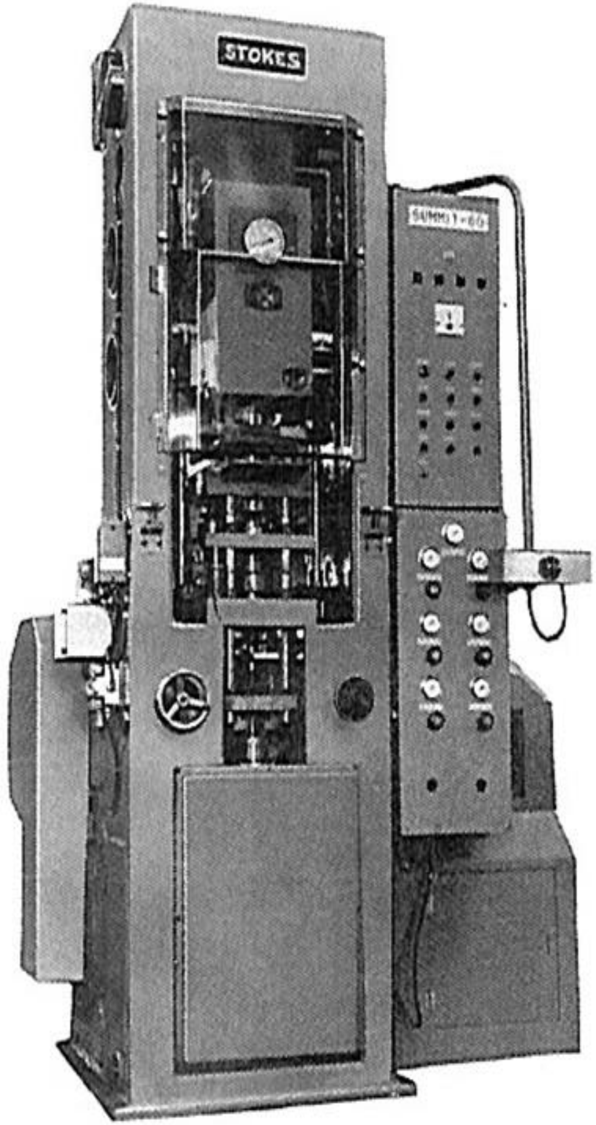
blade mixer

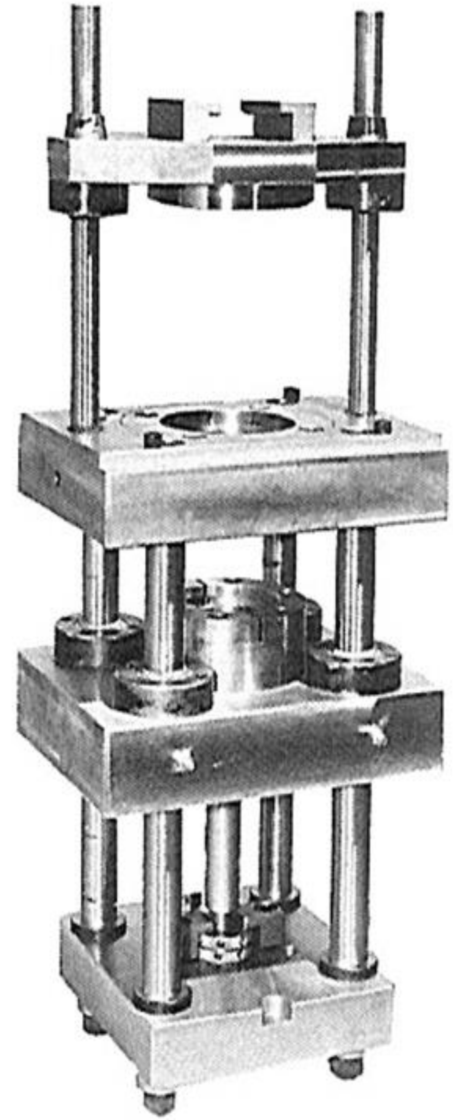
- High pressure is applied to powders to form them into required shape.
- Powders of different sizes are mixed for better compressibility.
- Then, they are blended with lubricants. Common lubricants are stearic acid, zinc stearate and powder graphite.
- Finally, they are compacted to shape under pressures of 20-1400 MPa.
- The part after compaction is called **a green compact (a green)**, meaning that the part is not yet fully processed.
- Green compact is not very strong. Final strength is obtained by sintering.





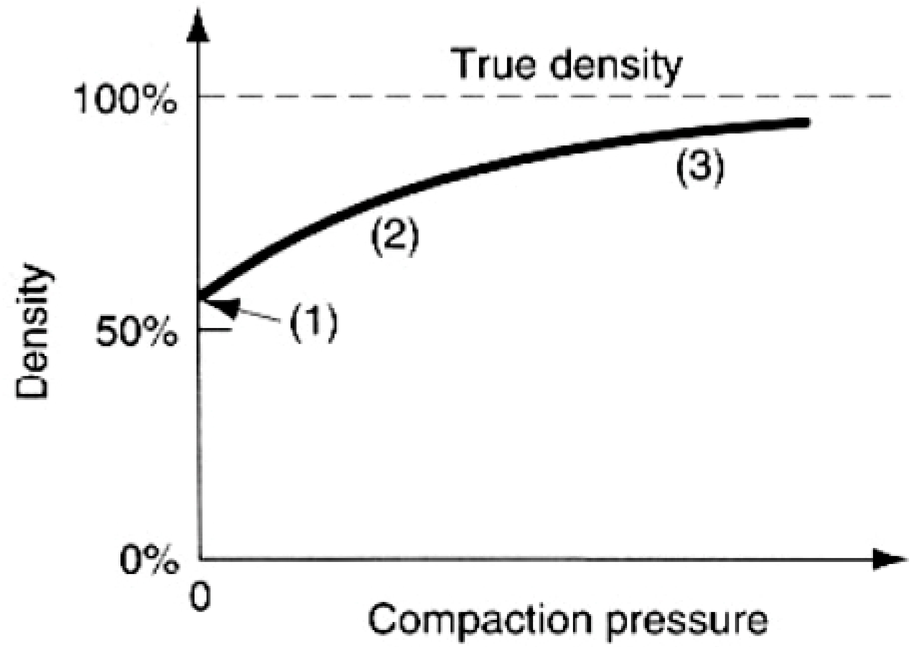
Left:	The press for compaction of metallic powders.
Right:	The removable die set allowing press to produce parts by one die set while another is being fitted to produce a second part.



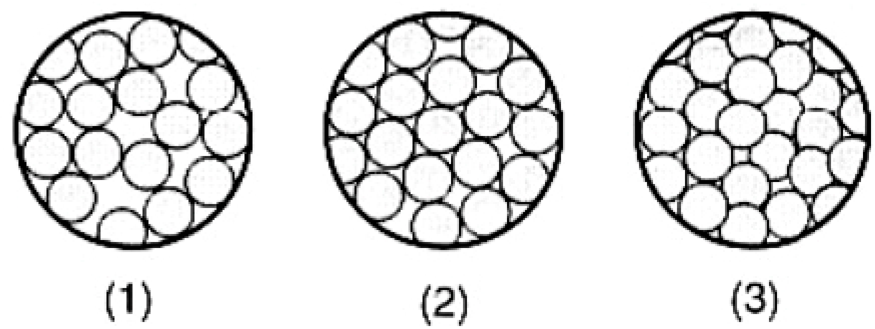


- The density of part after compaction (**green density**) is much greater than the starting material density, but is not uniform in the green.

- So, density and mechanical properties vary across part volume and depend on pressure in compaction:
  (1) initial loose powders after filling
  (2) repacking
  (3) deformation of particles

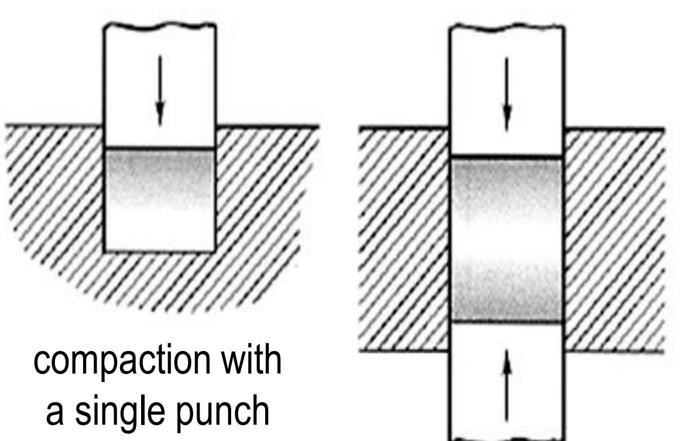


Metal	Pressure (Mpa)
Aluminum	70-275
Brass	400-700
Bronze	200-275
Iron	350-800
Tantalum	70-140
Tungsten	70-140



- Die cavity must be very smooth and must have a slight draft to facilitate removal of part.
- Wall friction prevents much of the pressure from being transmitted to the powder.
- Thus, there are two ways to minimize pressure loss and to improve the density distribution:
  - Application of **double acting press** and two moving punches in conventional compaction
  - **Cold isostatic pressing** (pressure applied from all directions to powder in a flexible mold)

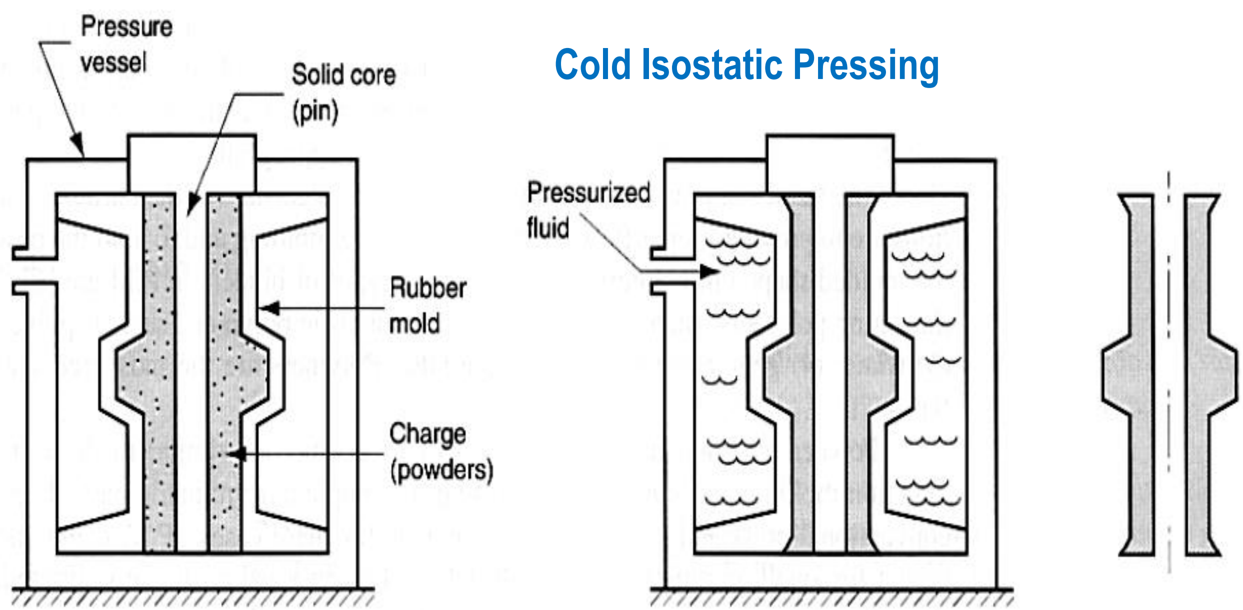
Double Acting Press



compaction with a single punch (non-uniform density)

double acting press with two moving punches (density distribution obtained)

Cold Isostatic Pressing



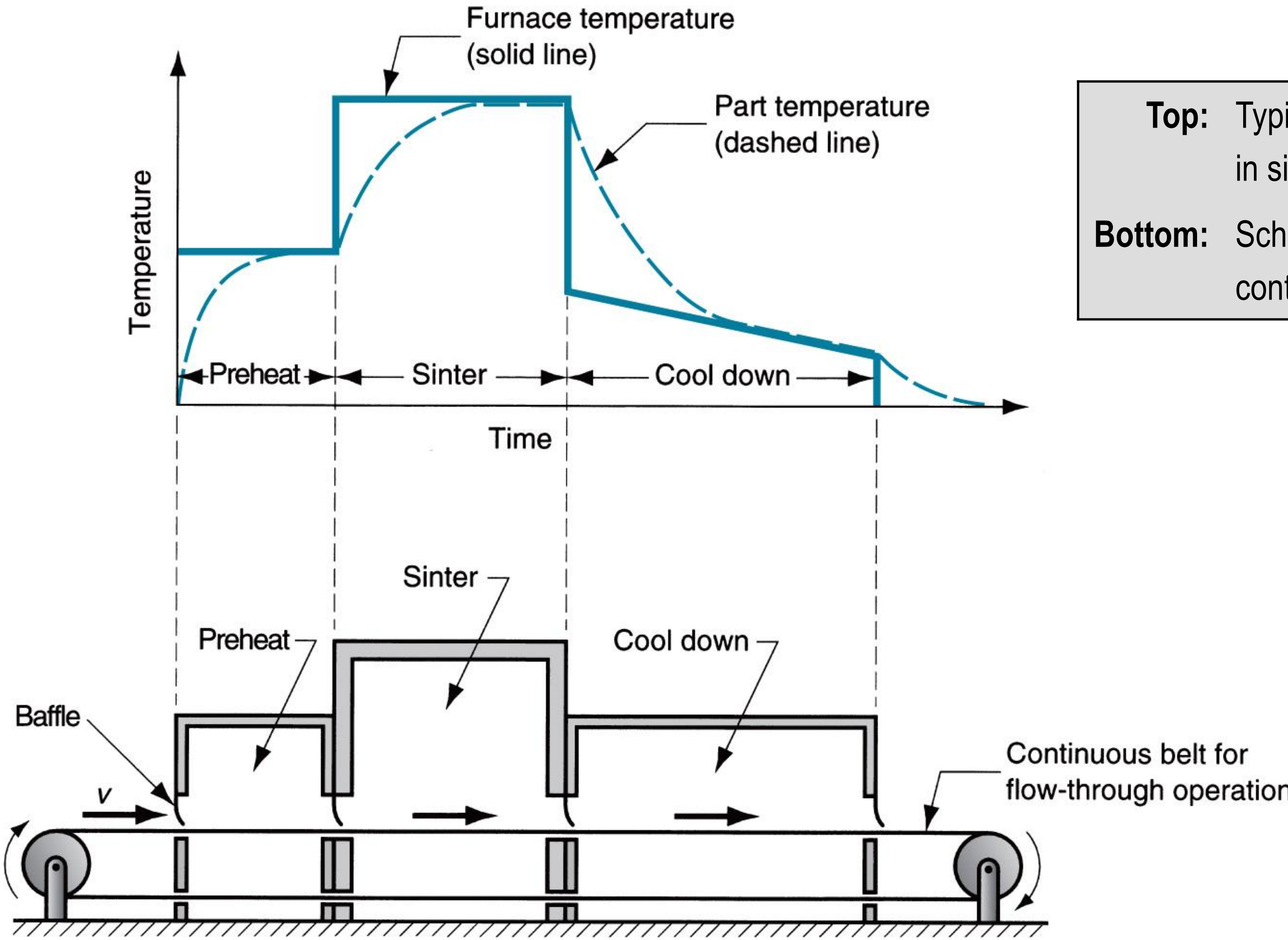
(1) Powders are placed in the flexible mold

(2) Hydrostatic pressure is applied against mold to compact the powders

(3) Pressure is reduced to remove part

- This is the operation of heating a green compact to an elevated temperature.
- Solid powders are welded together, and generally solid state diffusion takes place.
- There is shrinkage during sintering, which results in **densification**.
- Temperature is generally below the melting point of powders. However, one of the elements might melt (**liquid phase sintering**), which is commonly used in cemented carbide tool production.
- Steels are sintered at about 1100° C for about 20-40 minutes.
- To prevent reduction or oxidation of the powders, sintering furnaces are atmosphere controlled. Sintering of steel is done under dissociated **ammonia** (rich in nitrogen).

- Compressed metal powder is heated in a controlled-atmosphere furnace to a temperature below its melting point, but high enough to allow bounding of the particles.

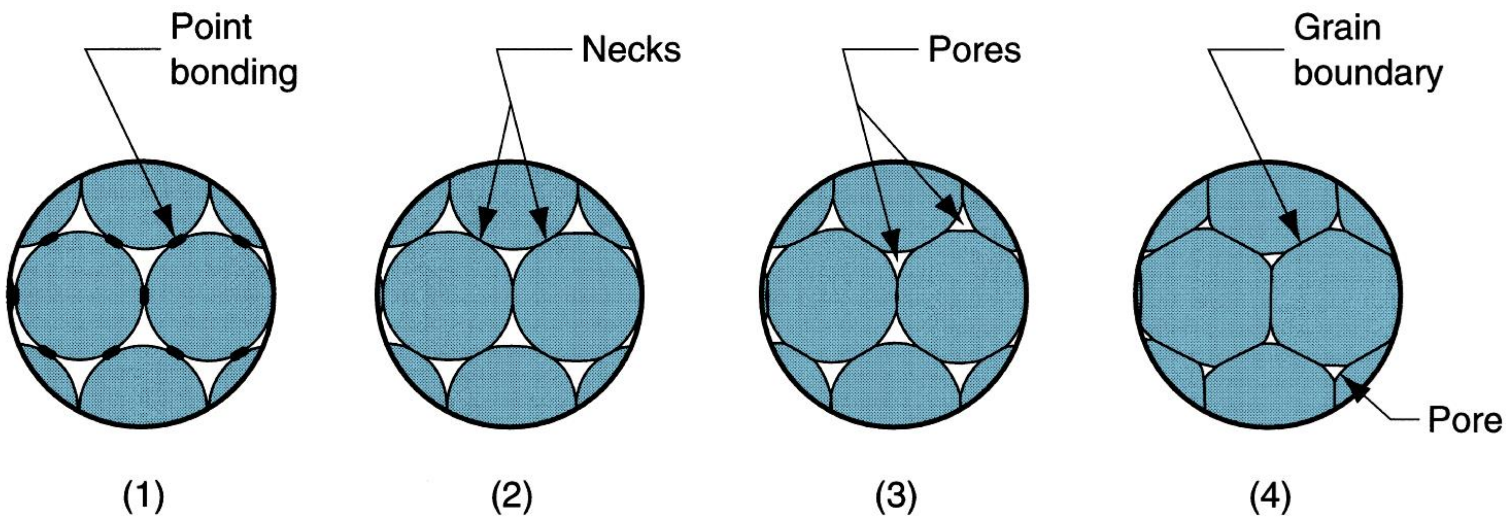


Top: Typical heat treatment cycle in sintering

Bottom: Schematic cross section of continuous sintering furnace

- **Primary driving force for sintering** is formation and growth of bonds between the particles.

- Microscopic-scale sketches show the changes occuring during sintering of metallic powders.



(1) Particle bonding is initiated at contact points

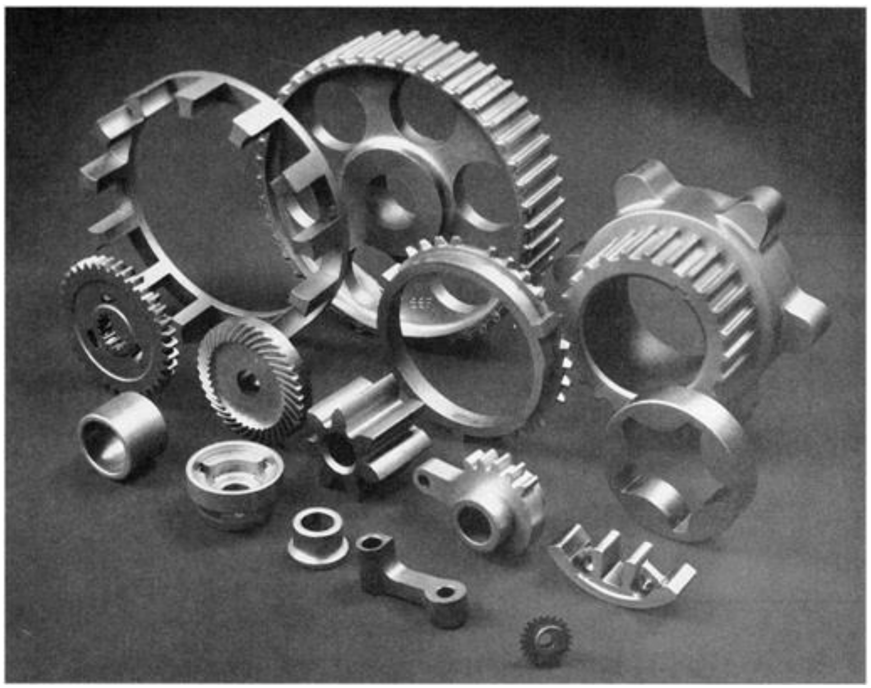
(2) Contact points grow into "necks"

(3) Pores between particles are reduced in size

(4) Grain boundaries develop between particles in place of necked regions

- **A number of secondary and finishing operations** can be applied after sintering.
- Among those, the most common process is **hot forging**.
- Porous sintered products have limited mechanical properties. By hot forging, full density products with equivalent mechanical properties to cast-rolled products can be produced.
- Other secondary and finishing operations are:
  - **Sizing** (cold pressing to improve dimensional accuracy)
  - **Coining** (cold pressing to press details into surface)
  - **Impregnation** (oil fills the pores of the part)
  - **Infiltration** (pores are filled with a molten metal)
  - **Heat treating**
  - **Plating**
  - **Painting**

- **PM has become competitive with:** casting, forging, and machining, for relatively complex parts with high strength and hard alloys.
- Although large-size parts (up to 20 kg) can be produced, most products are less than 1-2 kg.
- The largest tonnage of metals for PM is **steel** and **alloys of aluminum**. Others are: copper, nickel, tungsten, ceramic materials, etc.



Typical applications (but not limited to):

- Metallic Filters: Better strength than ceramic filters. Up to 80% porosity.
- Cemented Carbides: WC is mixed with Co powder, pressed to shape and liquid-phase sintered. Used as cutting tools and metal deformation die materials.
- Gears & Pump Rotors: Produced from iron powder mixed with graphite. About 20% porosity. After sintering, pores are infiltrated with oil for quiet operation.
- Porous Bearings: Made of copper, tin, and graphite powders. After sintering, sized and impregnated with oil. No need for lubrication during working (self-lubricated bearings).
- Magnets: Excellent small magnets (ferrites). Superior to cast magnets.
- Contact Parts: Must have wear resistance, refractoriness, good electrical conductivity. Combinations are: W-Cu, W-Co, W-Ag.

- The cemented carbides used in making cutting tools and drawing dies consists of carbides of:
  - **– tungsten (W)**
  - **– titanium (Ti)**
  - **– tantalum (Ta)**
  - **– molybdenum (Mo)**

  that are bounded with:
  - **– ductile cobalt (Co)**
  - **– nickel (Ni)**

Production of tunsgten carbide (WC) cutting tool by PM:

Tungsten Oxide

↓ Reduced by H_2

Tungsten

↓ Grinding

Tungsten Powders

↓ Mixing with Carbon

Heating (at 1500 °C for 2 hrs)

↓ Mixing with Co & Paraffin Wax

Compaction

↓

Sintering (at 850-1000 °C)

↓

Final Sintering (at 1350-1550 °C for 90 min)

↓

WC Tool

Advantages of PM

☺ PM parts can be mass produced to net/near-net shape (eliminating/reducing subsequent processing).

☺ PM involves little waste (about 97% of the starting powders converted to product). Superior to casting processes in which sprues, runners, risers are wasted in production cycle.

☺ Owing to the nature of starting material in PM, parts with a specified level of porosity can be made. This feature lends itself to the production of porous metal parts (e.g. filters, oil-impregnated bearings, gears).

☺ Certain metals that are difficult to fabricate by other methods can be shaped by PM. Tungsten is an example (tungsten filaments used in incandescent lamp bulbs are made using PM technology).

☺ Certain metal alloy combinations and cermets that cannot be produced by other methods can be formed by PM.

☺ PM is favorable to most casting processes in dimensional control of product. Tolerances of ±0.13 mm are held.

☺ PM production methods can be automated for economical production.

Disadvantages of PM

☹ High tooling and equipment costs.

☹ Expensive metallic powders.

☹ Difficulties with storing and handling metal powders.

☹ Limitations on part geometry since metal powders do not readily flow laterally in the die during pressing. Allowance must be given for ejection of the part from die after pressing.

☹ Variations in density throughout the part may be a problem (especially for complex part geometries).

➤The following **design requirements** are essential:

– Part shape must be as simple as possible.

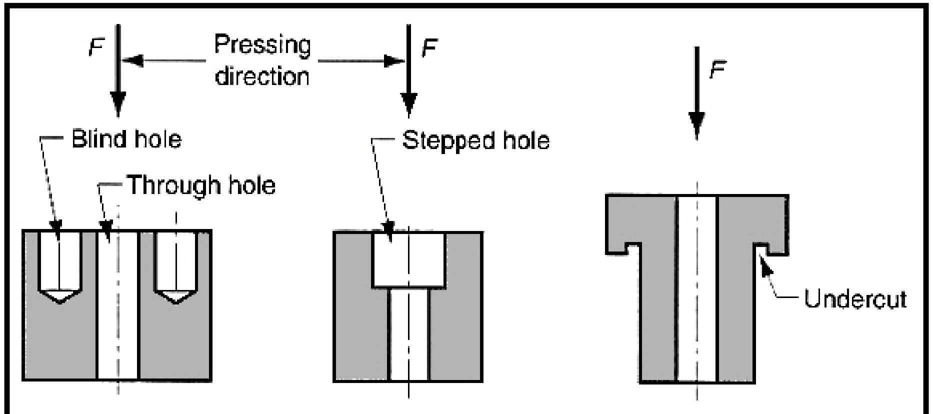
– Parts should be made with the widest tolerances (larger than 0.1 mm is possible).

– Holes and grooves must be parallel to direction of ejection (i.e. no undercuts on the side).

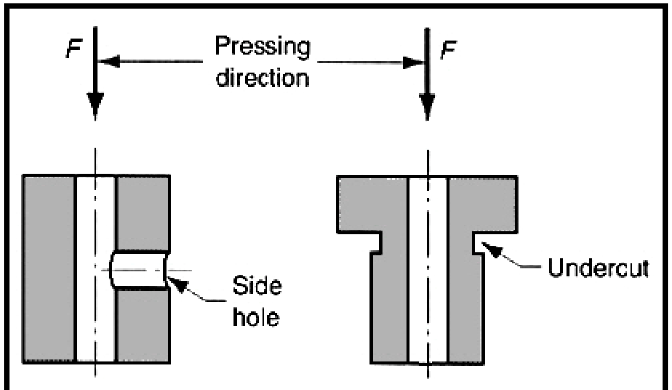
– Sharp corners, radii, thin section must be avoided.

– Minimum wall thickness is 1.5 mm.

– Radii and chamfers at corners are still possible, but certain rules should be observed.

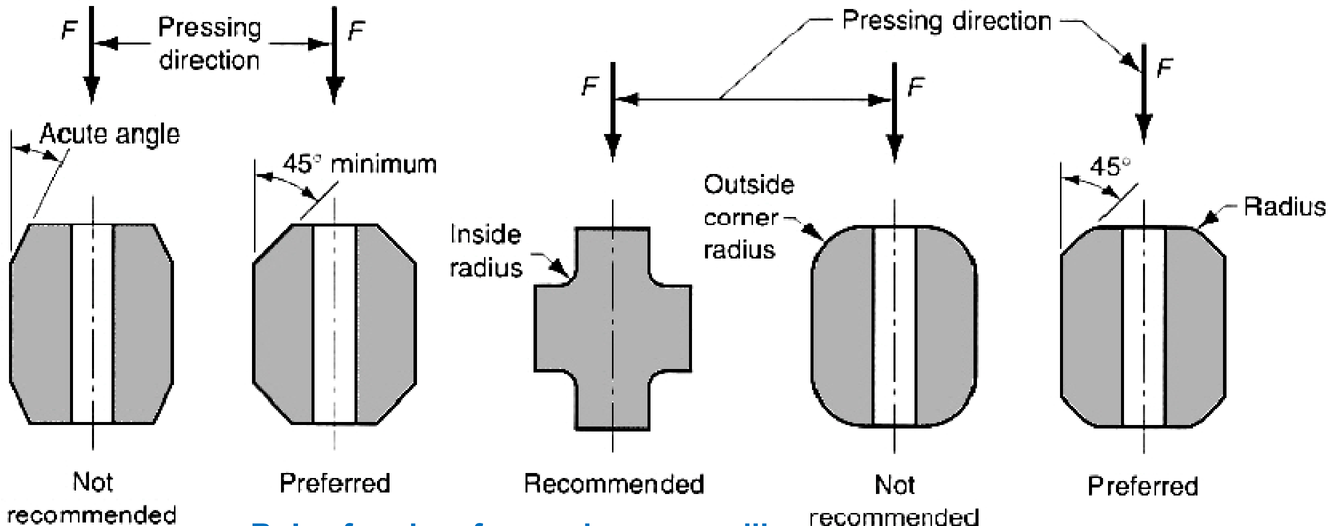


Permissible part features



Not recommended

(part ejection is impossible)



Rules for chamfers and corner radii